

## **General Disclaimer**

### **One or more of the Following Statements may affect this Document**

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

X-615-68-184

PREPRINT

NASA TM X- 63380

# ION, ELECTRON AND NEUTRAL TEMPERATURES DERIVED FROM ION COMPOSITION DISTRIBUTION

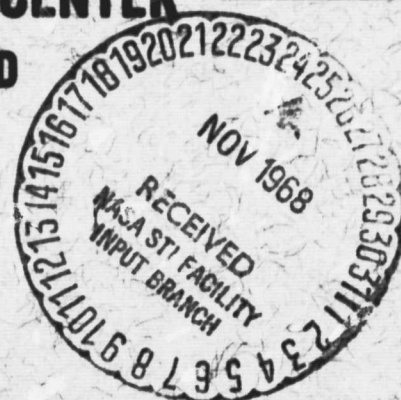
B. C. NARASINGA RAO

FACILITY FORM 602	<u>N 60-10728</u>	
	(ACCESSION NUMBER)	(THRU)
	<u>12</u>	<u>1</u>
	(PAGES)	(CODE)
	<u>TMX-63380</u>	<u>13</u>
	(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

MAY 1968



GODDARD SPACE FLIGHT CENTER  
GREENBELT, MARYLAND



# ION, ELECTRON AND NEUTRAL TEMPERATURES DERIVED FROM ION COMPOSITION DISTRIBUTION

B. C. Narasinga Rao\*  
Laboratory for Space Sciences  
NASA Goddard Space Flight Center  
Greenbelt, Maryland

Recently Brinton et al (1968) reported the positive ion mass spectrometer measurements obtained from the Geoprobe (Argo D-4 rocket) over an altitude range of 200-630 km at 1300 EST on March 2, 1966 above Wallops Island, Virginia. The ionic constituents measured were  $O^+$ ,  $N^+$ ,  $H^+$ ,  $He^+$ ,  $NO^+$ ,  $O_2^+$  and  $N_2^+$  (Fig. 1). The measurements showed  $O^+$  as the major constituent throughout the altitude range. Since the distribution of each ionic species is controlled by diffusive processes at higher heights and chemical processes at lower heights with an overlap in the intermediate heights (Bauer 1964) it is possible to derive the ion, electron and neutral temperatures from the composition data using the appropriate expressions.

Under diffusive equilibrium, the distribution of an ionic species  $X^+$  in an ion mixture having a mean ionic mass  $m_+$  is given by (Mange 1960, Bauer 1966)

$$n(X^+) = n_o(X^+) \exp \left\{ - \int_0^{z'} \left[ (m(X^+) - \frac{T_e}{T_e + T_i} m_+) \frac{g_o}{kT_i} + \frac{\frac{\partial}{\partial z'}(T_e + T_i)}{T_e + T_i} \right] dz' \right\} \quad (1)$$

---

\*NAS-NRC Resident Research Associate on leave from the National Physical Laboratory, New Delhi, INDIA

where  $T_e$  = electron temperature

$T_i$  = ion temperature (assuming all ions to be at the same temperature)

$z'$  = geopotential height

$g_0$  = acceleration of gravity at the earth's surface

As pointed out by Bauer (1964, 1966) an important feature of the diffusive equilibrium for ions is that, whereas the distribution of an individual ion species depends on  $T_e$  as well as  $T_i$ , the ratio of the two species in diffusive equilibrium depends on  $T_i$  only and, thus, the relative abundance of ionic species in diffusive equilibrium provides a measure of  $T_i$ .

From eq. (1) we obtain

$$\frac{\partial}{\partial z'} \ln \left[ \frac{n(X_1^+)}{n(X_2^+)} \right] = \frac{m(X_2^+) - m(X_1^+)}{kT_i/g_0} \quad (2)$$

The above equation can be used to derive  $T_i$  from the height gradient of the ratio of  $n(X_1^+)$  and  $n(X_2^+)$ , if both of them are in diffusive equilibrium. If they have not attained complete diffusive equilibrium in the region under study, the temperature derived from such a profile will be in error depending on the extent to which the distribution deviates from that of diffusive equilibrium. From the nature of distributions in Fig. 1 it appears that  $O^+$ ,  $H^+$ ,  $N^+$  and  $He^+$  are probably in diffusive equilibrium from 500 km upwards. From theoretical

studies it is estimated that whereas  $O^+$ ,  $H^+$  and  $He^+$  attain diffusive equilibrium by about 500 km or even lower altitude (Nisbet 1963, Bauer 1964, 1966; McElroy, 1965),  $N^+$  is still under chemical-cum-diffusive control (Bauer, 1966). It is thus reasonable to proceed with the assumption that  $O^+$ ,  $H^+$  and  $He^+$  are in diffusive equilibrium above 500 km to determine  $T_i$  using eq. (2). In fact, even for  $n(H^+)$  the theoretical scale heights calculated on the basis of diffusive equilibrium and using the temperatures and their gradients presented later, are 130 km, 180 km and 320 km which are close to the observed values of 100 km, 170 km and 320 km at altitudes of 500 km, 550 km and 600 km respectively.

The values of  $T_i$  derived from the height distributions of  $n(H^+)/n(O^+)$  and  $n(He^+)/n(O^+)$  using eq. (2) are shown in Fig. 2 for the height range of 350 to 600 km. It is seen that from about 450 km the  $T_i$  values derived from the two ratios are essentially the same. The mean values are  $1800^\circ K$  at 600 km,  $1500^\circ K$  at 550 km,  $1200^\circ K$  at 500 km and  $900^\circ K$  at 450 km. These values are comparable to the  $T_i$  values obtained by Thompson scatter experiment by Evans (1967) under similar conditions. The  $T_i$  values below 450 km derived from  $n(He^+)/n(O^+)$  distribution are in the range of  $250^\circ - 350^\circ K$  and are much too low compared to neutral temperature, though the  $T_i$  values derived from  $n(H^+)/n(O^+)$  are comparable to neutral temperature. This result suggests that the  $n(He^+)$

distribution is not in diffusive equilibrium below 450 km while  $n(O^+)$  distribution may correspond to diffusive equilibrium. The  $n(H^+)$  distribution, even if it is under chemical equilibrium, may still look like that of diffusive equilibrium, since both the distributions are similar for  $n(H^+)$  when it is a minor ion (Bauer 1966a).

We may utilize these values of  $T_i$  and its height variation to derive  $T_e$  as follows. The geopotential scale height  $H^*$  of the electron density distribution under diffusive equilibrium is given by

$$H^* = \frac{T_e + T_i}{\frac{g_0 m_+}{k} + \frac{\partial}{\partial z'}(T_e + T_i)} \quad (3)$$

Since  $H^*$  and  $m_+$  can be determined from the composition data, eq. (3) may be used to derive the  $T_e$  distribution. The calculation of  $T_e$  is performed by a method of successive iteration starting from  $\partial T_e / \partial z' = 0$ . The  $T_e$  values thus obtained are shown in Fig. 2. They are  $2900^\circ K$  at 600 km,  $2870^\circ K$  at 550 km,  $2790^\circ K$  at 500 km and  $2580^\circ K$  at 450 km. These values are in close agreement with the measured values of  $T_e$  by the electrostatic probe experiment by Brace et al (1968) on the same flight. These experimentally measured values are also shown in Fig. 2 for comparison.

With the values of  $T_i$ ,  $T_e$ ,  $\partial T_i / \partial z'$  and  $\partial T_e / \partial z'$ , thus obtained, it is possible to determine if the  $n(N^+)$  distribution is in diffusive equilibrium at higher altitudes. It is found that at 600 km, the scale height of the observed distribution is 275 km whereas the diffusive equilibrium scale height is 185 km. This difference implies the lack of diffusive equilibrium. However the distribution of  $n(N^+)$  can be used to calculate  $T_n$ . Bauer (1966) discussed the problem of  $n(N^+)$  distribution below and above its peak and showed that, above the peak, it is controlled by production through charge transfer between  $He^+$  and  $N_2$  and loss through the divergence of diffusive flux, and at still higher heights, by diffusive equilibrium. Above the peak and below the equilibrium region it is approximately given by

$$n(N^+) \approx \frac{1}{K} n(He) \propto \exp\left(-\frac{z'}{4}\right) \quad (4)$$

where  $K$  (a parameter dependent on diffusion velocity) may be assumed constant. Then the  $n(N^+)$  distribution follows the neutral helium distribution, which in turn, depends only on the neutral temperature. The values of  $T_n$  derived from the  $n(N^+)$  distribution in the height range of 350-450 km is  $760^\circ K$ .

It is also possible to determine  $T_n$  from the  $n(He^+)$  distribution in the height range of 350-400 km where it is mainly controlled by chemical processes. Under chemical

equilibrium  $n(\text{He}^+)$  is given by (Bauer 1966)

$$n(\text{He}^+) = \frac{I n(\text{He})}{\gamma n(\text{N}_2)} \propto \exp\left(\frac{z}{24}\right) \quad (5)$$

where  $I$  is the photoionization rate coefficient and  $\gamma$  is the charge exchange rate coefficient of  $\text{He}^+$  with  $\text{N}_2$ . In the above equation the charge exchange reaction of  $\text{He}^+$  with  $\text{O}_2$  for loss of  $\text{He}^+$  is not considered since  $n(\text{O}_2)$  is lower than  $n(\text{N}_2)$  by an order of magnitude in this altitude range. Then  $n(\text{He}^+)$  increases with height with a scale height corresponding to the neutral temperature and mass number 24. The value of  $T_n$  derived from  $n(\text{He}^+)$  distribution in the height range of 350-400 km is  $780^\circ\text{K}$ . This value is very close to that derived earlier from the  $n(\text{N}^+)$  distribution and is also close to the value of  $T_n$  derived from neutral  $\text{N}_2$  distribution as measured on the same flight by Pelz and Newton (1968).

In conclusion it is noted that the ion, electron and neutral temperatures may be derived from the ion composition data in a consistent way.

#### ACKNOWLEDGEMENTS

I am very grateful to Dr. S. Chandra and Dr. S. J. Bauer for many valuable suggestions and discussions. I wish to acknowledge with thanks Mr. H. C. Brinton and Mr. H. A. Taylor, Jr. for supplying their ion composition data.



## REFERENCES

1. Bauer, S. J., Some implications of a direct measurement of the hydrogen and helium ion distribution in the upper atmosphere, *J. Geophys. Res.* 69, 553-555, 1964.
2. Bauer, S. J., The constitution of the topside ionosphere, Electron Density Profiles in Ionosphere and Exosphere edited by J. Frihagen, pp.270-279, North-Holland Publishing Company, 1966a.
3. Bauer, S. J., Chemical processes involving helium ions and the behaviour of atomic nitrogen ions in the upper atmosphere, *J. Geophys. Res.* 71, 1508-1511, 1966b.
4. Brace, L. H., J. A. Findlay and H. G. Mayr, Measurements bearing on the particle and energy balance of the daytime midlatitude F region. Presented at the 49th Annual Meeting of the American Geophysical Union at Washington, D. C. April 8-11, 1968.
5. Brinton, H. C., M. W. Pharo III, H. G. Mayr and H. A. Taylor, Jr., Ion concentrations in the daytime F<sub>2</sub> region, measured at a time of rising solar activity. Presented at the 49th Annual Meeting of the American Geophysical Union at Washington, D. C., April 8-11, 1968.
6. Evans, J. V., Midlatitude F-region densities and temperatures at sunspot minimum, *Planet. Space Sci.* 15, 1387-1405, 1967.
7. McElroy, M. B. Excitation of atmospheric helium, *Planet. Space Sci.* 13, 403-433, 1965.

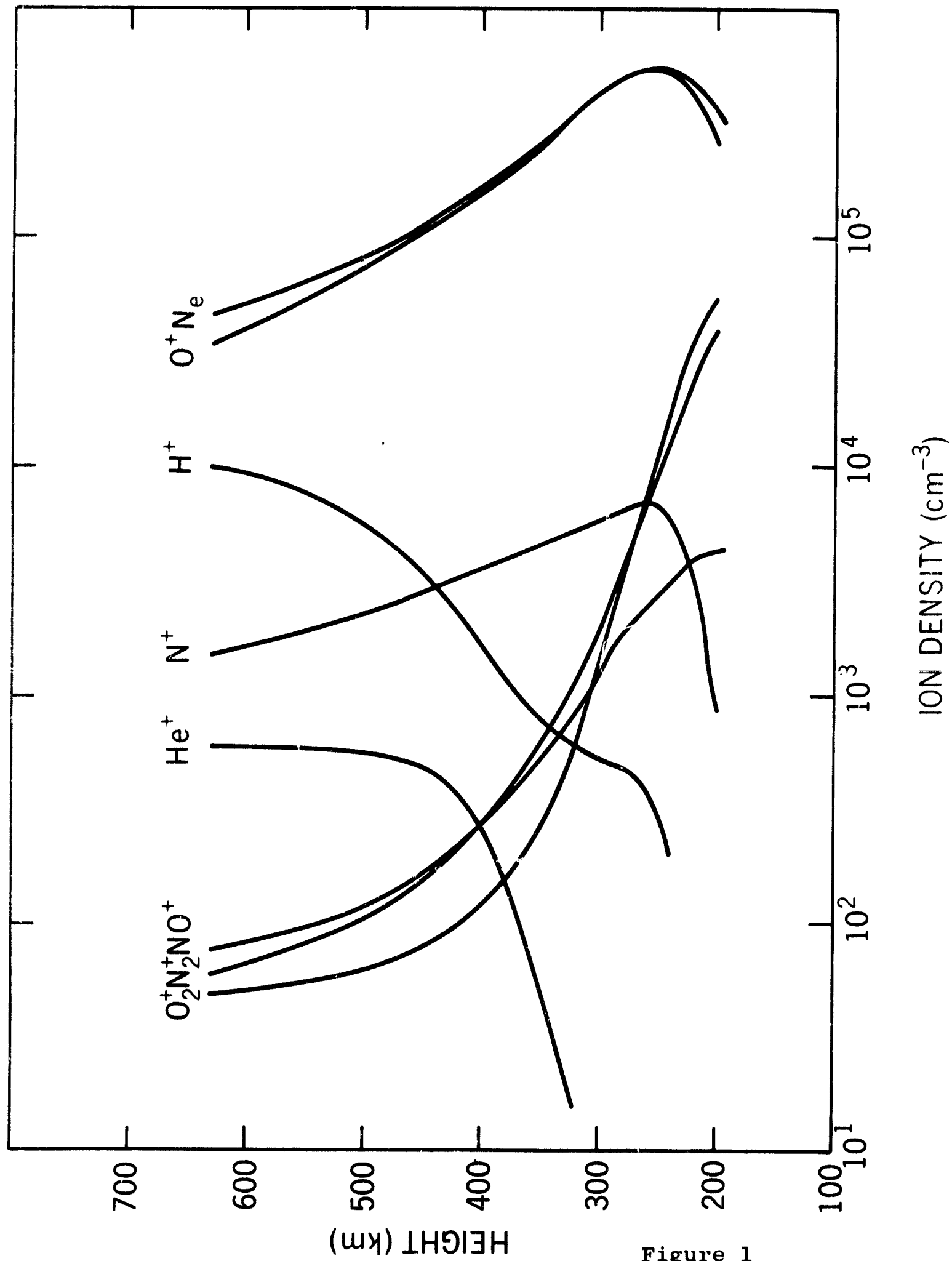
8.   Mange, P.,       The distribution of minor ions in electro-  
static equilibrium in the high atmosphere,  
J. Geophys. Res., 65, 3833-3834, 1960.
9.   Nisbet, J.S.,   Factors controlling the shape of the upper  
F region under daytime equilibrium conditions,  
J. Geophys. Res. 68, 6099-6112, 1963.
10.  Pelz, D. T.,   Neutral thermosphere density and temperature  
      and        measurements from the geoprobe pressure  
      G. P. Newton, gages, Presented at the 49th Annual Meeting  
                  of the American Geophysical Union at Washington,  
                  D. C., April 8-11, 1968.

### CAPTIONS FOR FIGURES

Fig. 1 Ion density distributions observed over Wallops Island, Virginia by positive ion mass spectrometer aboard the Geoprobe (Brinton et al, 1968).

Fig. 2 Ion, electron and neutral temperatures derived from ion composition data shown in Fig. 1. The  $T_e$  and  $T_n$  distributions shown by continuous lines are obtained by electrostatic probe by Brace et al (1968) and derived from neutral  $N_2$  distribution measurements by Pelz and Newton (1968) respectively made on the same flight.

WALLOPS ISLAND, VA. MARCH 2, 1966 1800 UT 1300 EST



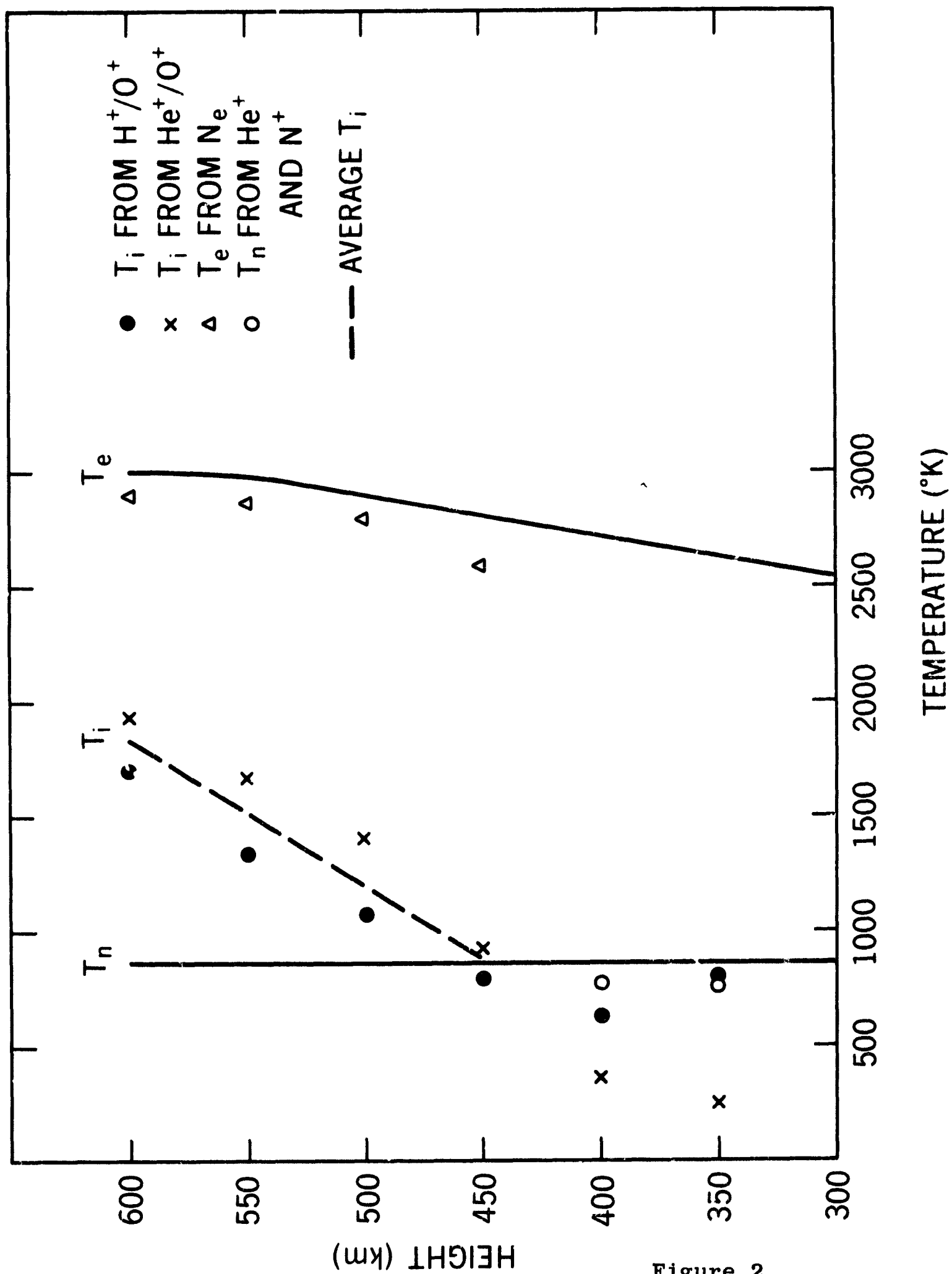


Figure 2